International Journal of Trend in Scientific Research and Development (IJTSRD)
Volume 5 Issue 4, May-June 2021 Available Online: www.ijtsrd.com e-ISSN: 2456 – 6470

Review on Doubling the Rate of SEFDM Systems using Hilbert Pairs

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ABSTRACT

A novel multi-carrier technique for spectrally efficient frequency division multiplexing (SEFDM) system for improving the spectral efficiency is discussed. A Hilbert pair is utilized as pulse-shaping filters. At the the Hilbert pulse pair is generated using the square-root raised cosine pulse and an equivalent matched filter configuration is utilized to generate the Hilbert pair at receiver. Simulations with different values of compression factor of the SEFDM signals were carried out to verify the data rate gain of the proposed system. The proposed system has no degradation in bit error rate performance with the data rate doubled relative to conventional SEFDM system. For system using turbo coding, there is significant BER improvement compared to uncoded transmission.

KEYWORDS: *Hilbert pair, turbo coding, SEFDM*

How to cite this paper: Padmam Kaimal "Review on Doubling the Rate of SEFDM Systems using Hilbert Pairs" Published in International Journal of Trend in Scientific Research and Development (ijtsrd), ISSN: 2456-6470, Volume-5 | Issue-4, June 2021, pp.825-828, URL: www.ijtsrd.com/papers/ijtsrd42348.pdf

IJTSRD42348

INTRODUCTION

Communication has changed the world in healthcare, aid and rescue operation on disasters, environmental protection, news reporting, education, business and entertainment. There is problem of severe spectrum scarcity due to high mobile traffic and more requirement of spectrum. Hence, we need novel technologies to increase the spectrum efficiency and energy-efficient wireless communications. Multicarrier modulation (MCM) is commonly-used as modern wireless communication technique. Orthogonal frequency division multiplexing (OFDM), is a great example of MCM which consists of N subcarriers spaced at 1/T intervals, where T is the period of symbols modulating each of the subcarriers, leading to the orthogonality among the subcarriers [2]. This prevents inter-carrier interference (ICI). In wireless standards such as 4G-LTE and 802.11a/g [2] OFDM has been widely adopted with various modulation schemes[11][12]. OFDM can optimize the spectral efficiency by utilizing adaptive bit and power-loading [4] [5].But, it should maintain the 1/T subcarrier spacing, and so for a given modulation, further improvement in spectral efficiency may be difficult to obtain.

Spectrally Efficient Frequency Division Multiplexing (SEFDM) is a technique used to generate non-orthogonal signals[8][13]. But, the improvement of bandwidth efficiency and capacity [9] is traded against the cost of the self-introduced inter-carrier interference, which is performance degradation and complexity. Signals can be generated using a Hilbert pair, which is a pair of pulse shapes that generate orthogonal signals. To improve further bandwidth efficiency relative to conventional SEFDM systems, the Hilbert pair is coupled with SEFDM. This is achieved by splitting the input symbols into two streams and modulating two sets of subcarriers, occupying the same spectral range. Then to give two output streams, the baseband complex modulated subcarriers are linearly added. For these streams, Pulse shaping and modulation/demodulation by a Hilbert pair ensures an added level of orthogonality and therefore there is no interference when separating and decoding a signal comprising two streams occupying the same bandwidth. This doubles the spectral efficiency and importantly without subjecting to power penalty. There is the increased system complexity. For Hilbert pair pulse shaping, we employ a root-Nyquist pulse shape especially the square root raised cosine (SRRC) pulse with a matched filter at the receiver. Results are verified using raw data transmission and Turbo coding.

SEFDM SIGNAL

The discrete-time representation for the k^{th} time sample of a single SEFDM symbol may be expressed as [14]

$$X[K] = \frac{1}{\sqrt{Q}} \sum_{n=0}^{N-1} s_n \; e^{j2kn\pi\alpha/Q} \qquad (1)$$

where s= $[s_0, s_1, \ldots \ldots, s_{N-1}]$ is the incoming M-ary quadrature amplitude modulation (M-QAM) signal vector for N subcarriers, Q is the the total number of discrete-time samples in one SEFDM symbol. ρ denotes the number of samples-per-symbol. Q =ρ N (ρ≥1, ρ∈Z) samples are there for the discrete time SEFDM scheme. For normalization, the factor 1/√Q is considered. OFDM and SEFDM are differentiated by the bandwidth compression factor (for OFDM α = 1 and for SEFDM α < 1), which determines the bandwidth saving in comparison to OFDM by (1−α)×100%

HILBERT PAIRS

The Hilbert pair originates from the in-phase (I) and quadrature (Q) components of the analytic signal $f_{+}(t)$ given by [15]:

$$f_{+}(t) = f(t) + j\cdot \hat{f}(t) \quad (2)$$

f (t)is a real-valued function. For constructing the orthogonal filter pair g (t) and ˆg (t), we multiply a given pulse shape p (t) with a Hilbert pair f (t) and ˆf (t), as is shown in the equation below [16]:

$$g(t) = p(t)f(t),\ \hat{g}(t) = p(t)\hat{f}(t). \quad (3)$$

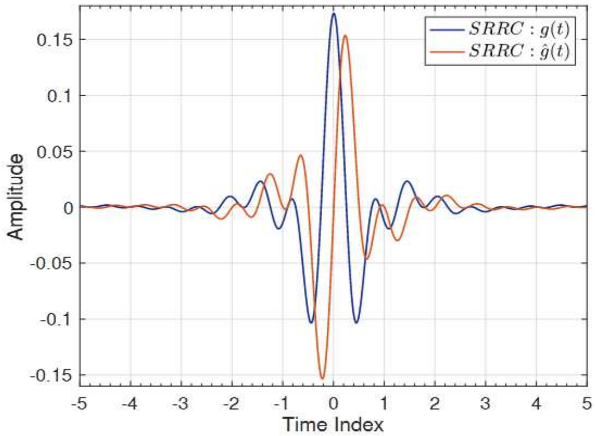

Fig 1.Time domain representation of Hilbert pair by SRRC

To form the Hilbert pair, a pair of sinusoidal carrier and co-sinusoidal carriers are utilized. So, the impulse response of the shaping pulse filters are the product of the pulse p (t)and the carrier pair of frequency f_c, given by [13]:

$$g(t) = p(t)\cos(2\pi f_c t),\ \hat{g}(t) = p(t)\sin(2\pi f_c t) \quad (4)$$

In this work, we utilize SRRC pulse, a root-Nyquist pulse which is commonly used, as the shape function p (t)of the filter pair. The usage of corresponding matched receiver in the system is assumed. In the expression of SRRC pulse p (t) in [1], the roll-off factor β∈[0,1] controls the excess bandwidth, T_s represents the symbol period. The filter bandwidth is equal to B= (1 +β)/2T_s. Fig.1 shows the time-domain representation of the filter pair pulse with β= 0.35 generated by SRRC

MODULATION SCHEME

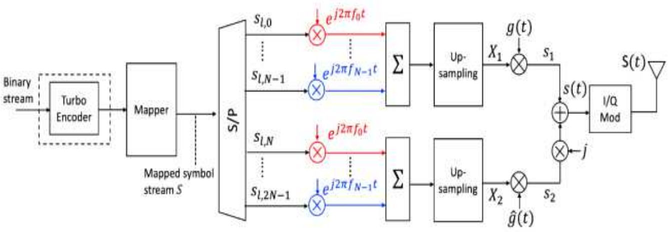

Fig 2 Simplified block diagram of transmitter

Figure 2, shows the block diagram of the transmitter of the proposed system g (t) and ˆg (t)are from equation (4). The portions in the same colour (red and blue)represent the same subcarrier. The incoming binary data stream is mapped either uncoded or with turbo coding of rate (1/3). Assuming M-QAM modulation, 2N complex symbols **S**= [$s_{l,0}, s_{l,1}, \ldots, s_{l,N-1}, s_{l,2N-1}$] are generated, where *l* represents the time sample index. The symbol stream is then split into two blocks of N= 16 parallel lower-rate sub-streams vectorised as **S**1= [$s_{l,0}, \ldots, s_{l,N-1}$] and **S**2= [$s_{l,N}, \ldots, s_{l,2N-1}$]. A bank of modulators is employed here to generate the SEFDM carriers with various values of compression factor α as 0.6, 0.8 and 1. So, S1 and S2 are modulated onto the same subcarrier frequencies and will be later separated in phase by the Hilbert pair. Both groups of signals are up-sampled via zero-padding between successive samples with the up sampling factor q= 4, then pulse shaping is done. $X_1$and X_2indicates the up-sampled SEFDM signal on the two independent frames, and hence the process of pulse shaping can be expressed as:

$$s_1(t) = g(t) * X_1,\ s_2(t) = \hat{g}(t) ** X_2 \quad (5)$$

g (t)and ˆg (t)are a normalised Hilbert pulse pair obtained from (6). Since ideal filters of infinite length are impractical, the filters have 10 symbols length span. The outputs of the two orthogonal filters are added up, after multiplying the second stream by j to give s (t), which can be expressed by

$$s(t) = s_1(t) = + j\cdot s_2(t) \quad (6)$$

The obtained signal is converted to RF signal by modulation and then passed through the wireless channel, that is assumed to be a simple additive white Gaussian noise (AWGN) channel.

DEMODULATION SCHEME

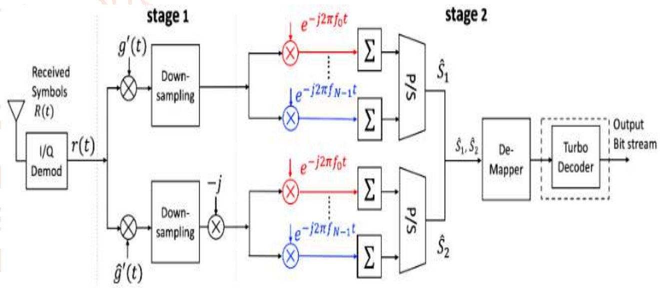

Fig 3 Simplified block diagram of receiver

The block diagram of the receiver in Fig 3 is shown. The portions in the same colour (red and blue) represent the same subcarrier. It consists of two stages. The first stage separates two symbol streams and then demodulates the signal in each. The second stage uses time-reversed matched filtering without advanced detection methods. By flipping the Hilbert pulse pair in the time domain, the matched filtering pair at the first stage can be obtained, as given by [13]:

$$g'(t) = g(-t),\ \hat{g}'(t) = \hat{g}(-t) \quad (7)$$

The matched pair g′ (t) and ˆ g′ (t)separate the received signals into two sub-streams after the down sampling and decimation. At the second frame −j is represented with the negative sign for recovering the signal as in the bottom arm of transmitter. If two groups of symbols are separated, matched filtering along with hard decision will work in the manner as in traditional SEFDM or OFDM systems. At the second stage, the matched filtering is equivalent to the conjugate complex of the subcarriers matrix Φ∗. The demodulation process can be expressed as [14]:

$$\hat{S} = \Phi^{*} R = \Phi^{*}(X+W) = \Phi^{*}\Phi S + \Phi^{*} W \quad (8)$$

ˆS represents the demodulated signal, Φ is the Q-by-N subcarrier matrix, Φ^{*} is N-by-Q matrix, the input X is defined by equation (1) and W indicates the noise vector. The correlation matrix C is constructed as [14]:

$$C = \Phi^{*}\Phi \quad (9)$$

Ideally the correlation indicates an N-by-N unitary matrix, then the received signals will be recovered if the noise-associated term that was introduced is removed or suppressed. As shown in equation, the AWGN noise is expanded by the complex conjugate of the subcarrier matrix. Since we use the orthogonal Hilbert pair, no degradation is found in the correlation matrix C, the proposed system is anticipated to have an identical BER performance when compared to the traditional SEFDM[1].

The recovered complex symbol streams, termed as ˆS1 and ˆS2 are input into the demapper block serially. Once turbo coding is used, based on the investigation in [17], 5 iterations can be optimal to impede the introduced inter carrier interference of SEFDM[1].

PERFORMANCE CONSIDERATION

The performance of proposed system is assessed by finding the BER for different α values. For the purpose of comparison, tests are carried out on both traditional SEFDM and the novel system. MATLAB is used to verify the mathematical model.

The normalized spectrum of the conventional SEFDM signal and the proposed transmitted signal is compared in fig 4. when the compression factor α is equal to 0.8 and 1 (OFDM).It is known that the inherent non-orthogonality of SEFDM signal, resulting in the compression of the frequency spacing between adjacent subcarriers, having the spectral efficiency gain when compared to OFDM signal. The spectral efficiency typically describes the maximum data rate that can be transmitted over a particular bandwidth B and hence can be measured by their ratio[1]. Smaller the α, the higher the spectral efficiency that can be attained due to the reduced bandwidth consumption.

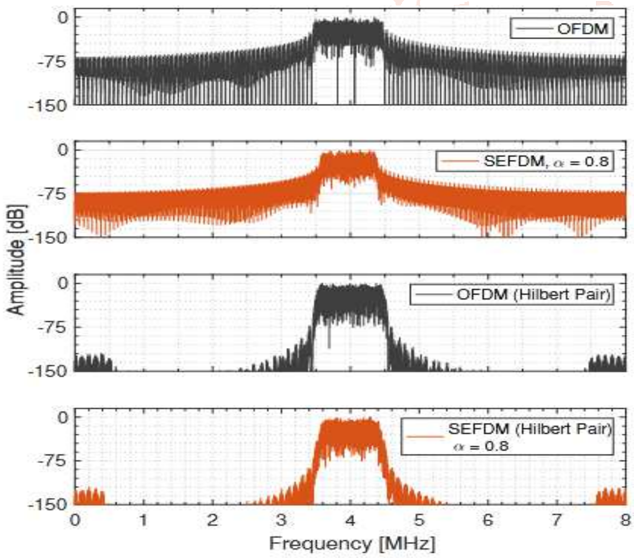

Fig 4.Spectrum Comparison[1].

Figure 4 shows the spectrum of OFDM, SEFDM with α= 0.8, OFDM using Hilbert pulse pair, SEFDM using Hilbert pulse pair with α= 0.8 is shown. It is found that the designed signal filtered by the Hilbert pair occupies the same bandwidth at the same carrier frequency as compared to the SEFDM. In traditional SEFDM, the frequency spectrum carries only one symbol stream. However, with the constant spectrum utilization the frequency spectrum of the proposed signal carries two independent 4-QAM symbol streams. This doubles the data rate. The spectral efficiency of the proposed signal can be is twice the spectral efficiency of the SEFDM [1]when using the same α. This shows that by using the Hilbert pulse pair, the spectral efficiency is doubled[1].

The BER performance of the proposed system using Hilbert pulse pair was observed based on different values of compression factor α. When α ≤ 0.8, when MF is employed, the system will not lead to good BER results. Turbo coding is added to improve performance. So the coding is effective in enhancing the BER of the proposed system[1].

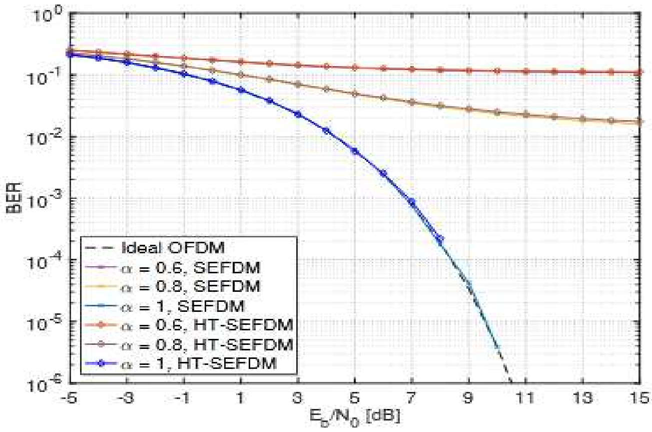

Fig.5 Comparison of BER performance of SEFDM signalwith and without Hilbert SRRC pulse shaping with various values of α[1].

Figure 5 shows the BER performance of the signal generated from the proposed design (given in Fig. 2) versus. It is is found that the proposed system achieves identical BER performance compared to the conventional OFDM (α= 1) and SEFDM (α= 0.8, α= 0.6). If compression factor α is reduced, the error performance degrades rapidly, which is matching with the theoretical results[1]. It can be concluded that the use of Hilbert pulse pair as shaping pulses doubles the spectral efficiency of SEFDM This occurs without incurring error penalties. Figure 6 shows the numerical results of the precoded system (in Fig. 2), showing the substantial BER reduction when compared to the un-coded signal[1].

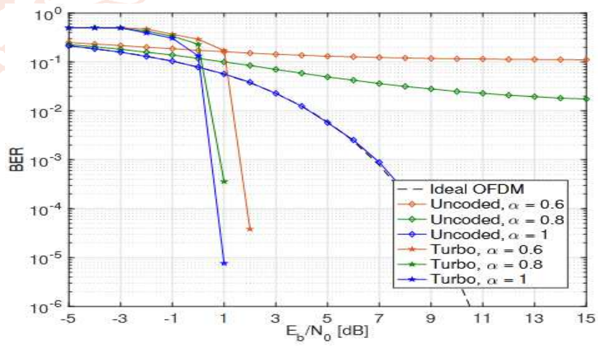

Fig.6. Comparison of BER performance of SEFDM signal with Hilbert SRRC pulse shaping with various values of α with and without turbo coding [1].

CONCLUSION

A signal processing technique to improve the spectral efficiency of SEFDM systems is discussed. A new transceiver structure to generate the new signal format, employing Hilbert pulse pair as shaping pulses is proposed. The advantage is that it helps in doubling the spectral efficiency by transmitting two different complex symbols simultaneously and within the same occupied spectrum, without degrading the BER performance. For system utilising turbo coding, there is significant BER improvement compared to uncoded transmission.

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